US008916810B2

(12) **United States Patent**
Geswender et al.

(10) **Patent No.: US 8,916,810 B2**
(45) **Date of Patent: Dec. 23, 2014**

(54) **STEERABLE SPIN-STABILIZED PROJECTILE**

(75) Inventors: **Christopher E. Geswender**, Green Valley, AZ (US); **Richard Dryer**, Oro Valley, AZ (US); **Paul Vesty**, Tucson, AZ (US)

(73) Assignee: **Raytheon Company**, Waltham, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 542 days.

(21) Appl. No.: **13/075,277**

(22) Filed: **Mar. 30, 2011**

(65) **Prior Publication Data**

US 2012/0248239 A1 Oct. 4, 2012

(51) **Int. Cl.**
F42B 10/06 (2006.01)
F42B 10/64 (2006.01)
F42B 10/26 (2006.01)

(52) **U.S. Cl.**
CPC ***F42B 10/64*** (2013.01); ***F42B 10/26*** (2013.01)
USPC **244/3.23**

(58) **Field of Classification Search**
USPC 244/3.15, 3.21, 3.23, 3.24, 3.26, 3.28, 244/3.29, 3.1
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,585,935 A * 6/1971 Birkigt 102/240
4,512,537 A * 4/1985 Sebestyen et al. 244/3.21
4,964,593 A 10/1990 Kranz
5,114,095 A * 5/1992 Schroppel et al. 244/3.28
5,235,930 A 8/1993 Pendleton
6,073,880 A 6/2000 Voigt et al.
6,135,387 A * 10/2000 Seidel et al. 244/3.15
6,360,987 B1 3/2002 Sallaee et al.
7,004,425 B2 * 2/2006 Okada et al. 244/3.29
7,267,298 B2 * 9/2007 Leininger 244/3.24
7,354,017 B2 4/2008 Morris et al.
7,412,930 B2 8/2008 Smith et al.
2002/0117580 A1 * 8/2002 Rupert et al. 244/3.24
2008/0223977 A1 9/2008 Dryer
2010/0282895 A1 11/2010 Geswender
2010/0320330 A1 12/2010 McMickell et al.
2012/0175458 A1 * 7/2012 Geswender 244/3.24
2012/0175459 A1 * 7/2012 Geswender et al. 244/3.24

OTHER PUBLICATIONS

U.S. Appl. No. 12/843,921, filed Jul. 27, 2010.

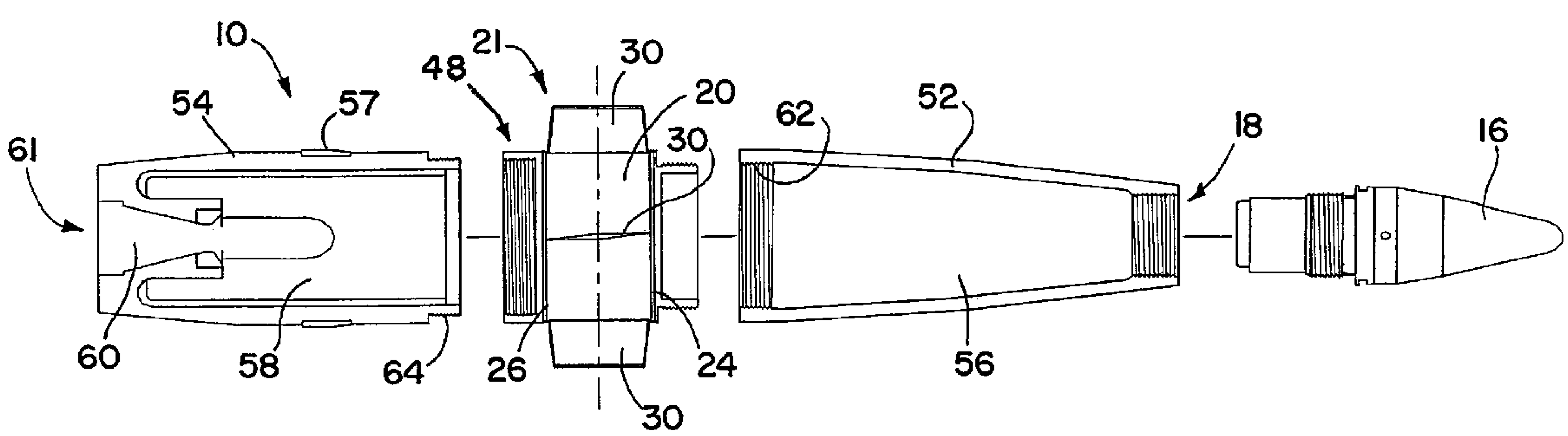
* cited by examiner

Primary Examiner — Valentina Xavier
(74) *Attorney, Agent, or Firm* — Renner, Otto, Boisselle & Sklar, LLP

(57) **ABSTRACT**

A spin-stabilized projectile has a collar around the middle of its spun fuselage, longitudinally spanning a center of mass of the projectile. The collar includes lift-producing aerodynamic surfaces. Positioning the collar relative to the spinning fuselage produces a direct lift force on the projectile that may be used to steer the projectile. Since the projectile is constantly spinning, the positioning may be accomplished by a brake, such as a magnetic brake or a fiction brake, that allows the collar to be positioned substantially fixed relative to inertial space, with the collar not rotating with the fuselage about a longitudinal axis of the projectile. Since the lift force is applied close to the center of mass of the projectile, the steering occurs with no substantial change in the angle of attack of the projectile.

20 Claims, 3 Drawing Sheets



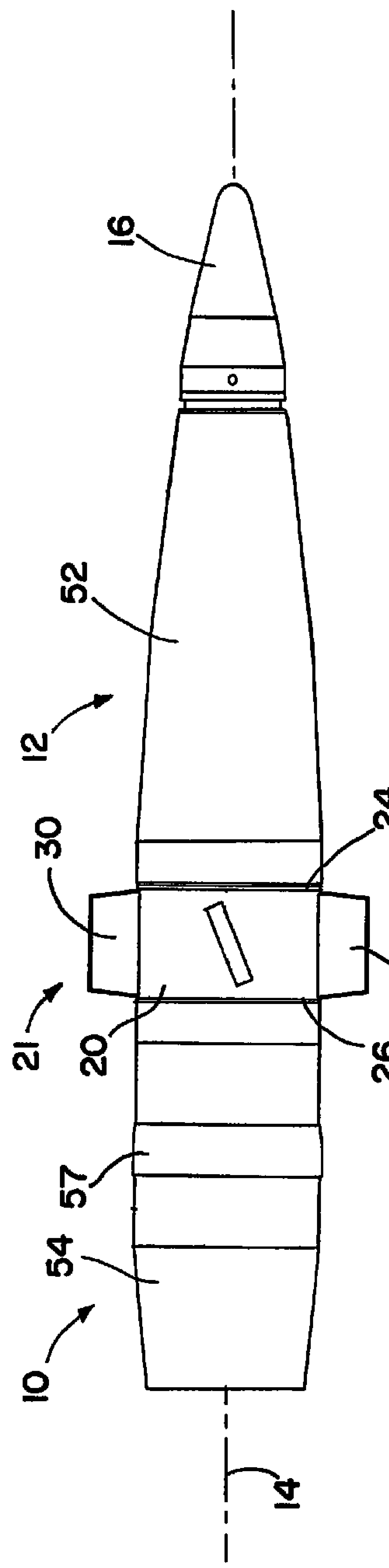

16
52
12
30
24
30
21
20
26
57
54
10
14

FIG. 1

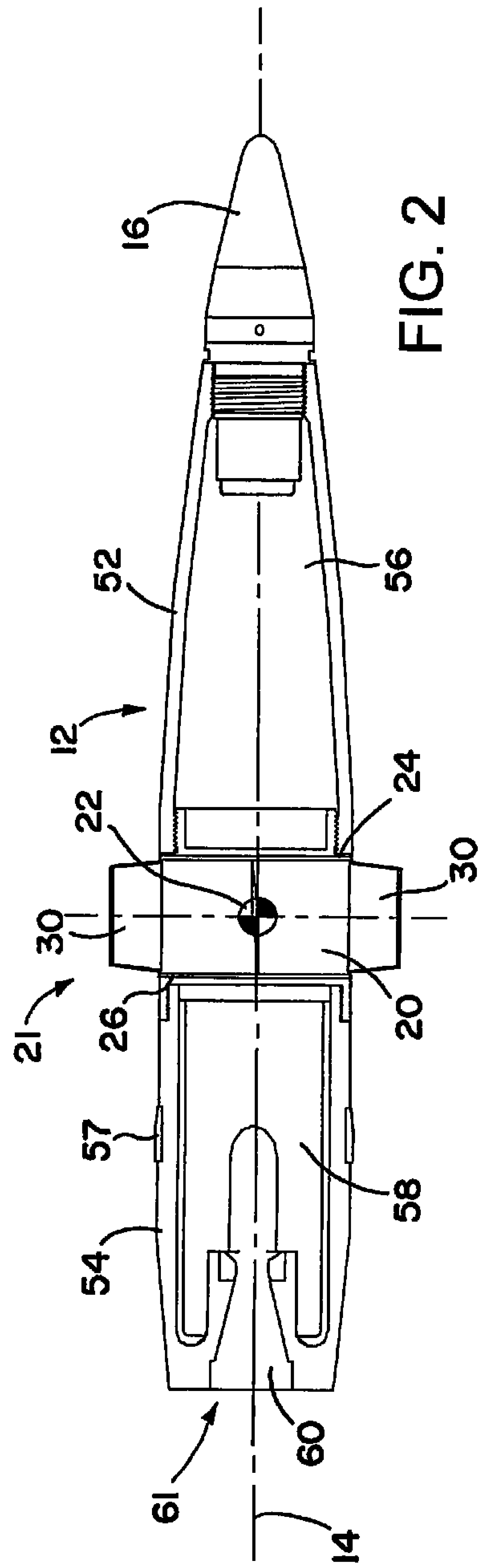

16
52
56
12
22
24
30
30
21
26
20
57
58
54
60
61
14

FIG. 2

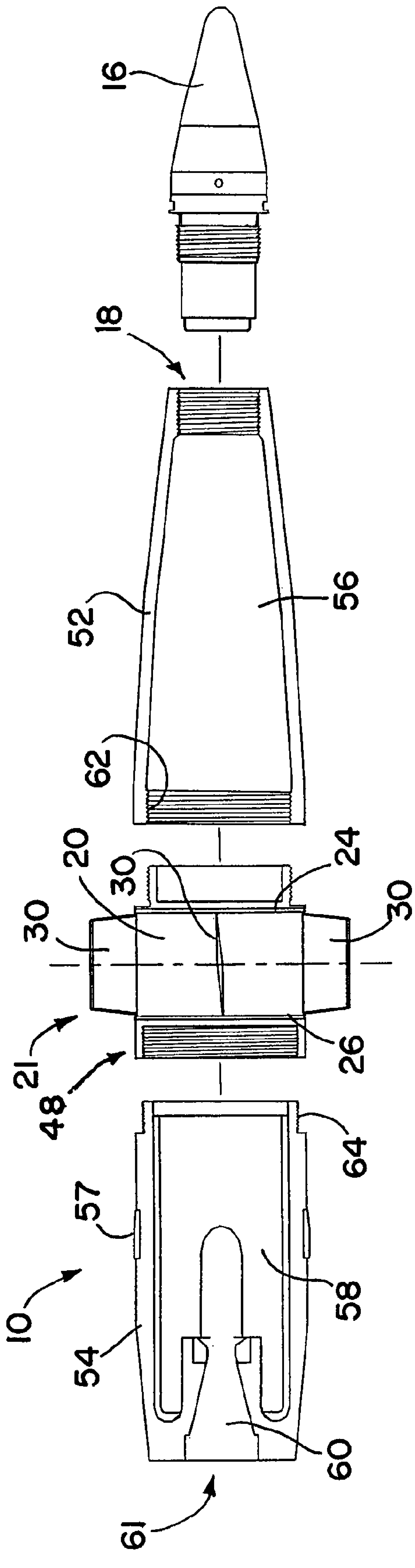

16
18
52
56
62
20
30
24
30
30
21
48
26
10
57
58
54
64
60
61

FIG. 3

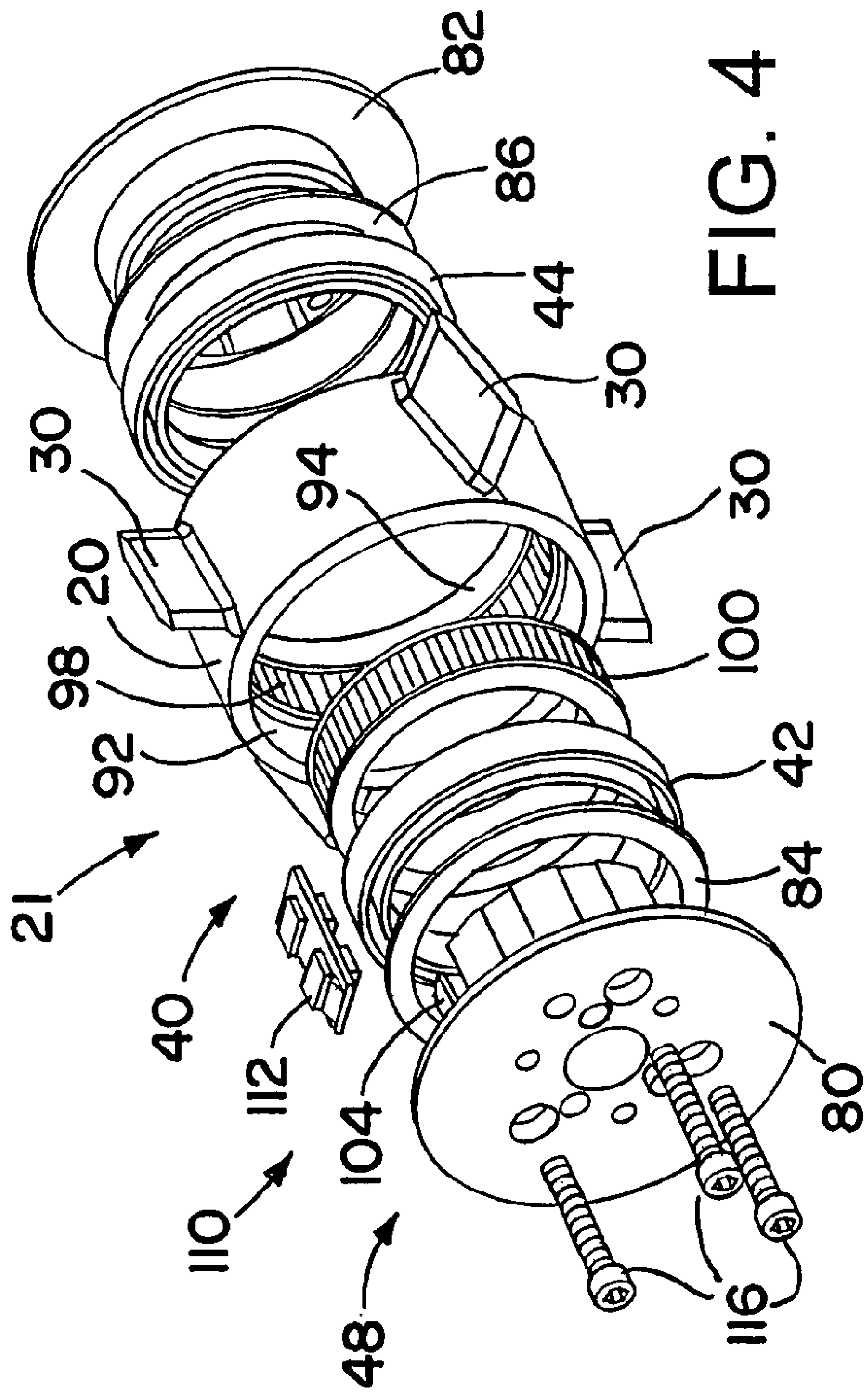

82
86
44
30
30
30
94
20
30
98
100
92
42
21
84
40
112
80
104
110
116
48

FIG. 4

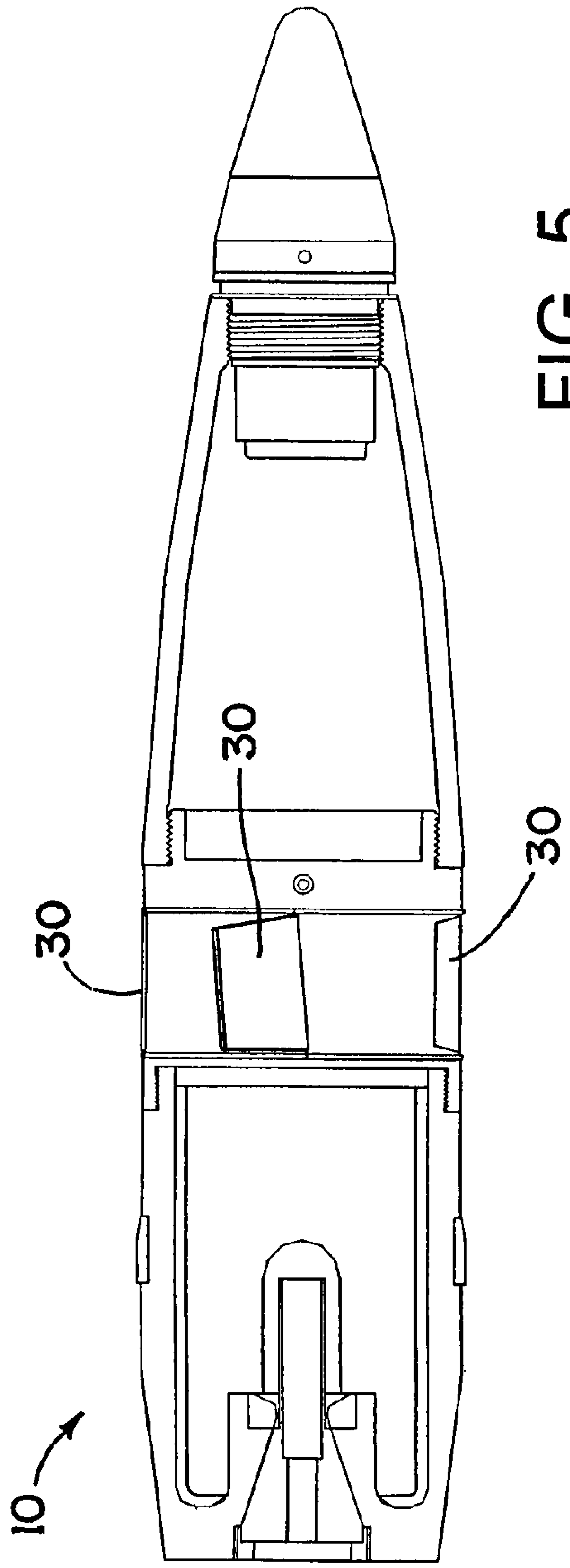


FIG. 5

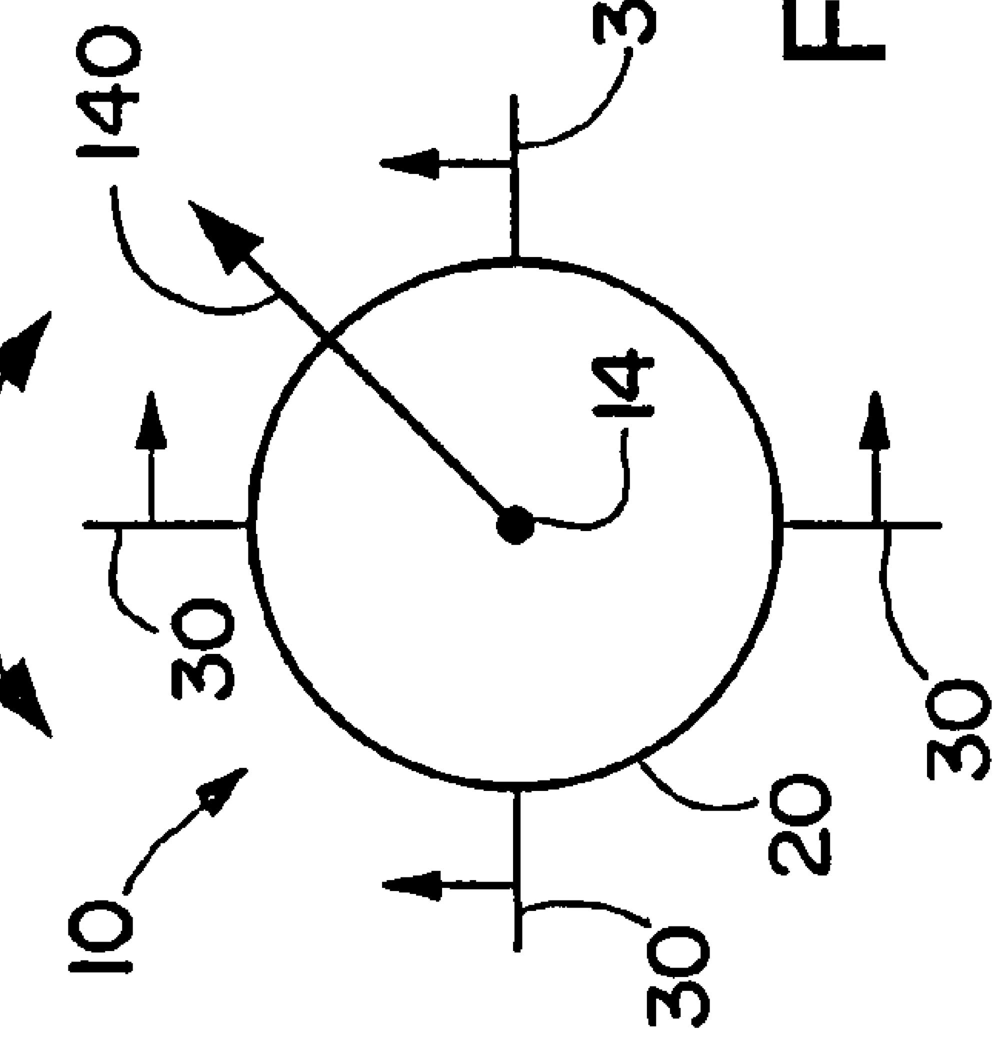


FIG. 7

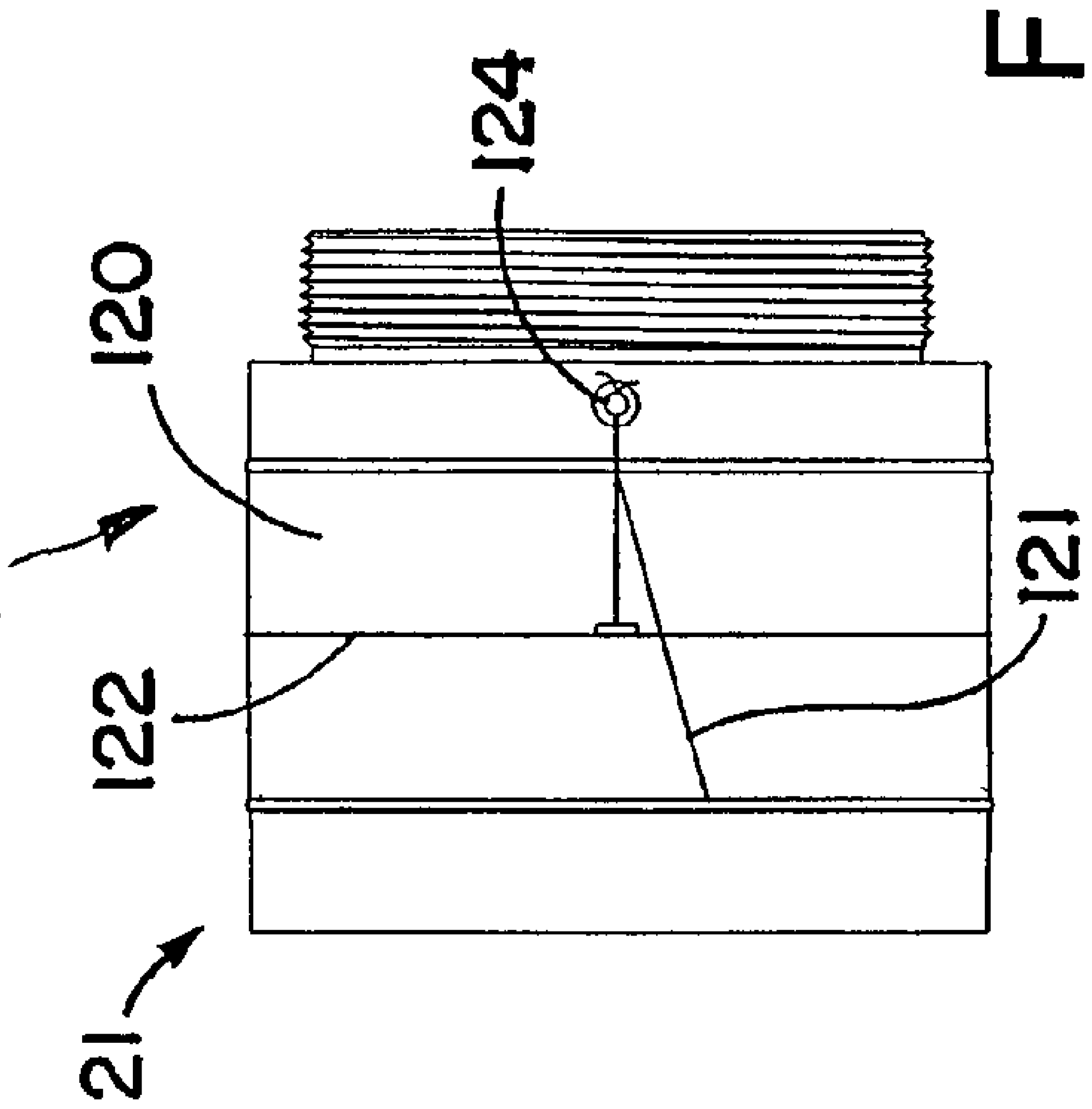


FIG. 6

STEERABLE SPIN-STABILIZED PROJECTILE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is in the field of projectiles.

2. Description of the Related Art

The effectiveness of a projectile may be limited by a variety of constraints. Two such constraints are range and accuracy. For instance, an artillery-fired projectile may have a limited range relating to a maximum muzzle velocity for a given combination of projectile, barrel, and propellant. Frequently, targets beyond this limited range cannot be effectively reached. Additionally, an artillery-fired projectile may have a fixed trajectory upon firing. As a consequence, an unguided projectile that is not accurately aligned upon firing may miss its intended target. Other factors can reduce the accuracy of the unguided projectile, such as atmospheric conditions, variations in the aerodynamic properties of a given projectile, and/or the like.

Limited range and accuracy may have a number of effects in combat situations. Limited range may require engaging the enemy at a close proximity. Poor accuracy may require engaging the enemy for an extended duration with multiple rounds. In these scenarios, the parameters of the artillery-fired projectile may increase the cost of operations, yet provide a weapon system having a low effectiveness. This may adversely affect the logistics burden of the system and the lives of combatants who must experience longer times to service combat targets.

Existing systems for modifying the trajectory of a projectile include systems having actuatable control surfaces configured to steer the projectile. While these systems may serve to guide the projectile, such systems may also add substantial complexity and weight to the projectile, and the inherent drag of the aerodynamic controls may reduce the range of the projectile.

SUMMARY OF THE INVENTION

According to an aspect of an invention, a spin-stabilized projectile has lift-producing aerodynamic surfaces that longitudinally span a canter of mass of the projectile.

According to a further aspect of the invention, a projectile includes: a spin-stabilized fuselage; and a collar having lift-producing aerodynamic surfaces. The collar is positionable relative to the spin-stabilized fuselage by relative rotation about a longitudinal axis of the projectile. The collar longitudinally spans a center of mass of the missile.

According to a still further aspect of the invention, a method of maneuvering a projectile includes: spinning a fuselage of the projectile to stabilize the projectile; and steering the projectile by positioning a collar of the projectile relative to the fuselage, thereby causing lift-producing aerodynamic surfaces of the collar to produce a direct net steering force on the projectile. The collar longitudinally spans a center of mass of the projectile.

To the accomplishment of the foregoing and related ends, the invention comprises the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative embodiments of the invention. These embodiments are indicative, however, of but a few of the various ways in which the principles of the invention may be employed. Other objects, advantages and novel features of

the invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The annexed drawings, which are not necessarily to scale, show various aspects of the invention.

FIG. **1** is a side view of a projectile according to an embodiment of the present invention.

FIG. **2** is a cross-sectional view of the projectile of FIG. **1**.

FIG. **3** is an exploded view of the projectile of FIG. **1**.

FIG. **4** is an exploded view of the control activation system of the projectile of FIG. **1**.

FIG. **5** is a view of the projectile of FIG. **1**, showing the lift-producing surfaces in a stowed condition.

FIG. **6** is a side view of the control activation system of the projectile of FIG. **1**, showing components of a constraint system for keeping the lift-producing surfaces in a stowed condition.

FIG. **7** is an end schematic view illustrating lift forces produced by the lift-producing surfaces of the projectile of FIG. **1**.

DETAILED DESCRIPTION

A spin-stabilized projectile has a collar around the middle of its spun fuselage, longitudinally spanning a center of mass of the projectile. The collar includes lift-producing aerodynamic surfaces. Positioning the collar relative to the spinning fuselage produces a direct lift force on the projectile that may be used to steer the projectile. Since the projectile is constantly spinning, the positioning may be accomplished by a brake, such as a magnetic brake or a fiction brake, that allows the collar to be positioned substantially fixed relative to inertial space, with the collar not rotating with the fuselage about a longitudinal axis of the projectile. Since the lift force is applied close to the center of mass of the projectile, the steering occurs with no substantial change in the angle of attack of the projectile.

FIGS. **1-4** show a spin-stabilized projectile **10** that has a spinning (rolling) fuselage **12**. The spinning fuselage **12** is spun (rolled) about a longitudinal axis **14** of the projectile **10**, in order to stabilize the course of the projectile **10** during flight. The spinning may be imparted during launch of the projectile **10**, such as by use of rifling in a launch tube, and/or it may be imparted by torque-producing canted fins (not shown), which may be deployed during flight of the projectile **10**. A fuze kit **16** is coupled to a forward end of the fuselage **12**, in a fuze well **18**. The fuze kit **16** may be used to detonate an explosive that is located inside the fuselage **12**. The fuze kit **16** may provide other functions, such as providing guidance control for the projectile **10**, controlling the steering of the projectile **10** toward a target or other intended destination.

The aerodynamic forces for steering the projectile **10** are provided by a roll collar **20** that is part of a control activation system (CAS) **21**. The roll collar **20** longitudinally spans a center of mass **22** of the projectile **10**. The center of mass **22** is on the longitudinal axis **14** of the projectile **10**. In longitudinally spanning the center of mass **22**, a front edge **24** of the collar **20** is longitudinally forward of the center of mass **22**, and a back edge **26** of the collar is longitudinally aft of the center of mass **22**. The roll collar **20** has a series of lift-producing aerodynamic surfaces **30**, such as wings, on its perimeter. The lift-producing aerodynamic surfaces **30** may be an even number of surfaces, for instance consisting of two, four, or six lift-producing surfaces. The surfaces **30** may be even distributed about the outer surface (perimeter) of the collar **20**. More broadly, pairs of the surfaces **30** may be diametrically opposed to each other.

The collar **20** is positionable in the inertial frame, relative to the projectile, to produce a resultant force on the projectile **10**, in order to provide steering to the projectile **10**. As described in greater detail below, the projectile **10** includes a mechanism **40** for positioning the collar **20** about the longitudinal axis **14**. This allows the collar **20** to remain in a desired circumferential orientation about the longitudinal axis **14**, even as the fuselage **12** spins about the longitudinal axis **14**.

The collar **20** is mounted on bearings **42** and **44**, such as ball bearings, to allow the collar **20** to rotate freely relative to a fixed inner section **48** that is fixedly attached to the fuselage **12**. The fixed section may be threaded onto or otherwise secured to a forward fuselage portion **52** and an aft fuselage portion **54**. The forward fuselage portion **52** houses a payload **56**, such as a suitable explosive. The aft fuselage portion **54** has an obturator **57** on it, and houses a propellant **58** for propelling the projectile **10**. The propellant **58** is ignited by an igniter **60** at the back end of the projectile **10**. Once ignited, the propellant **58** produces pressurized gasses that are ejected from the projectile **10** through a nozzle **61**, providing forward thrust. The aft fuselage section **54** might also be more explosive payload in place of a propulsive capability, or the projectile could be modular in design so that the aft section can be selected by the user to be propulsive or explosive, thereby providing the user the flexibility of selecting maximum range or maximum lethality for the munition.

In the illustrated embodiment the forward fuselage portion **52** has internal threads **62**, and the aft fuselage portion **54** has external threads **64**. The threads **62** and **64** engage the inner section **48** of the control activation system **21**. The inner section **48** and the collar **20** may be parts of a single assembly, such as the CAS **21**, with the bearings **42** and **44** allowing rotation of the collar **20** relative to the inner section **48**.

A representative mechanism **40** for positioning the collar **20** may be a brake that provides some engagement between the collar **20** and the fuselage **12**. The collar **20** may configured such that the surfaces **30** naturally provide a counter-rotation to the collar **20**, a rotation that is about the longitudinal axis **14** in a direction opposite from the direction of spin of the fuselage **12**. The combination of the natural counter-rotation of the collar **20** and the selective partial coupling of the collar **20** to the fuselage **12** may be used to keep the collar **20** stable relative to an external frame of reference, and/or to selectively position the collar **20** as desired about the longitudinal axis **14**.

The mechanism **40** may be a friction brake or a magnetic brake that can partially couple the movement of the collar **20** and the fuselage **12**. An example of a friction brake is shown in U.S. Pat. No. 7,412,930.

FIG. **4** shows further details of the control activation system **21**, specifically the inner section **48**, and its relation to the bearings **42** and **44** and the collar **20**. The example shown in FIG. **4** is a magnetic brake. The inner section **48** includes a main housing **80** and an aft closure **82**, on opposite ends. The housing **80** and the closure **82** may be configured to engage the fuselage portions **52** and **54** (FIGS. **1-3**), such as with threaded extensions (not shown in FIG. **4**).

The inner section includes a pair of Belleville washers **84** and **86**. The Belleville washer **84** is between the housing **80** and the bearing **42**, and the Belleville washer **86** is between the aft closure **82** and the bearing **44**. The Belleville washers aid in maintaining proper positioning of the bearings **42** and **44** relative to the collar **20**. The bearings **42** and **44** are located on indentations **92** and **94** on an inner surface of the collar **20**. The indentations **92** and **94** are opposite sides of a series of magnets **98** along the inner surface of the collar **20**.

An armature **100** is radially inward of the magnets **98**. The armature **100** is mounted on a circular ledge **104** of the main housing **80**. This allows the armature **100** to move along with the fuselage **12**, rotating about the longitudinal axis **14** as the fuselage **12** spins. A control system **110** may be used to provide current to the armature **100**, as needed, to provide the desired resistance against movement of the collar **20** (including the magnets **98**) relative to the fuselage **12** (including the armature **100**). The control system **110** is represented in FIG. **4** as a MOSFET printed circuit board set **112**, one of three such sets. The control system **110** may be connected in a wired connection or a wireless connection with a guidance control in the fuze kit **16** (FIG. **1**). The control system **110** may take any of a wide variety of forms.

The assembly of parts shown in FIG. **4** is held together by a series of bolts **116** that extend from the housing **80** to the closure **82**. There may be a central opening in the assembly that allows passage of other components of the projectile **10** (FIG. **1**), such as wires for communication of signals.

Turning now to FIG. **5**, the lift-producing surfaces **30** are deployable, able to be deployed from an initial collapsed/stowed configuration shown in FIG. **5**. In the collapsed/stowed configuration the surfaces **30** are against the body of the projectile **10**. The surfaces **30** may have some flexibility when in the collapse/stowed configuration, and may automatically deploy to the deployed configuration (FIGS. **1** and **2**) during flight. The deployment may come shortly after the projectile **10** exits a launch tube or other launcher.

In the stowed configuration the lift-producing surfaces **30** may be biased toward deployment unless constrained. An example of a suitable constraint and deployment system **118** is illustrated in FIG. **6**. A sheet metal cover **120** contains and protects the lift-producing surfaces (FIG. **5**) in the stowed configuration. The cover **120** is slit along a cut line **121**, and is held in place with a retaining wire **122** that is connected to a pyrotechnic device **124**. Firing the pyrotechnic device **124** causes the retaining wire **122** to be loosened and discarded from the projectile **10**. This in turn lets the cover **120** separate from the projectile **10**, allowing the lift-producing surfaces **30** to deploy. Further details regarding such a deployment system may be found in co-owned U.S. Patent Pub. 2010/0282895, the description and figures of which are incorporated by reference.

The projectile **10** and the collar **20** may rotate about the projectile axis **14** at any of a variety of suitable frequencies. For example the fuselage **12** may spin at a frequency of about 200 Hz. The collar **20** may be configured to counter-rotate at a frequency of about 20 Hz, in the absence of any braking force. These numbers are only example values.

FIG. **7** illustrates the forces on the projectile **10** from the lift-producing surfaces **30**. Diametrically-opposed surfaces **30** produce forces in the same direction (up and to the right in the illustrated embodiment), but of different magnitudes. Together the surfaces **30** generate a resultant force **140** on the projectile **10**, and a resultant torque **144** on the collar **20**. The resultant force **140** is used to steer the projectile **10**, and the resultant torque is used to provide the counter-rotation of the collar **20** (in the absence of a braking force).

The resultant force **140** is applied at or near the center of mass of the projectile **10**. The longitudinal location of the resultant force **140** (the longitudinal location of the center of the lift forces produced by the surfaces **30**) may be within 1 cm (0.4 inches) of the center of mass, or more narrowly within 0.63 cm (0.25 inches) of the center of gravity. This is for a projectile having an overall of 76 cm (30 inches), for example.

By acting at (or very close to) the center of gravity the force **140** provides a steering lift to the projectile **10**, without changing the angle of attack of the projectile **10**. This is in contrast to steering that relies on precession to induce steering forces on a projectile. Precession requires a change in orientation (angle of attack), which results in drag that decreases overall range. The projectile **10**, which is steered without substantial change in angle of attack, does not suffer the same drag as precession-steered projectiles. Therefore the projectile **10** has a longer range than other steered spin-stabilized projectiles. The projectile **10** combines the accuracy and steering authority of fin-stabilized projectiles with the simplicity and low cost of prior spin-stabilized projectiles that utilize gyroscopic (precession-based) steering.

In the embodiment described above the lift-producing aerodynamic surfaces **30** may be fixed in their positions on the collar **20**. That is, their angles of attack are fixed, with the collar being rotated as a unit. An alternative arrangement is have the lift-producing surfaces shifting in angle of attack, for example by use of a swash plate to alter the angle of attack of cyclically as the fuselage **12** spins. The variable angle-of-attack lift-producing surfaces would still be on a collar, which could be selectively rotated to position the lift-producing surfaces. The swash plate system may be similar in some respects to the systems disclosed in co-owned U.S. patent application Ser. No. 13/005,175, filed Jan. 12, 2011, titled "Guidance Control for Spinning or Rolling Projectile," the description and figures of which are incorporated by reference.

Although the invention has been shown and described with respect to a certain preferred embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

What is claimed is:

1. A projectile comprising:

a spin-stabilized fuselage; and

a collar having lift-producing aerodynamic surfaces;

wherein the collar is positionable relative to the spin-stabilized fuselage by relative rotation about a longitudinal axis of the projectile; and

wherein the collar longitudinally spans a center of mass of the projectile.

2. The projectile of claim **1**, wherein the aerodynamic surfaces have a fixed angle of attack.

3. The projectile of claim **1**, wherein the aerodynamic surfaces have a variable angle of attack.

4. The projectile of claim **1**, further comprising a brake that positions the collar relative to the spin-stabilized fuselage.

5. The projectile of claim **4**, wherein the brake is a magnetic brake.

6. The projectile of claim **5**, wherein the collar includes a series of magnets that interact with an armature connected to the fuselage.

7. The projectile of claim **4**, wherein the brake is a friction brake.

8. The projectile of claim **4**, wherein, during flight and in the absence of braking by the brake, the lift-producing surfaces provide a torque that rotates the collar.

9. The projectile of claim **8**, wherein the torque rotates the collar in an opposite direction from spin of the fuselage.

10. The projectile of claim **1**, wherein the lift-producing aerodynamic surfaces are deployable from a stowed condition.

11. The projectile of claim **1**, wherein a center of lift of the lift-producing surfaces is longitudinally within 1 cm (0.4 inches) of the center of mass.

12. The projectile of claim **1**, further comprising a pair of bearings that allow the collar to rotate relative to the fuselage.

13. A method of maneuvering a projectile, the method comprising:

spinning a fuselage of the projectile to stabilize the projectile; and

steering the projectile by positioning a collar of the projectile relative to the fuselage, thereby causing lift-producing aerodynamic surfaces of the collar to produce a direct net steering force on the projectile;

wherein the collar longitudinally spans a center of mass of the projectile.

14. The method of claim **13**, wherein the steering occurs without substantial change in an angle of attack of the projectile.

15. The method of claim **13**, wherein the positioning includes rotating the collar about the longitudinal axis.

16. The method of claim **13**, wherein the positioning includes:

counter-rotating the collar, using lift from the lift-producing surfaces, in a direction opposite that of the spinning of the fuselage; and

braking the movement of the collar so as to apply a torque on the collar from the fuselage.

17. The method of claim **16**, wherein the braking includes magnetic braking.

18. The method of claim **17**, wherein the magnetic braking includes interaction between an armature connected to the fuselage and a series of magnets that rotate with the collar.

19. The method of claim **16**, wherein the braking includes friction braking.

20. The method of claim **13**, wherein a center of lift of the lift-producing surfaces is longitudinally within 1 cm (0.4 inches) of the center of mass.

* * * * *